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EXPERIMENTAL STUDIES ON EFFECT OF STIFFENER CONFIGURATION ON COMPRESSIVE STRENGTH OF STIFFENED PANELS

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ABSTRACT

In this present work, comparative analysis of integrated stiffened panels and the flat plate is studied. Glass Fiber Reinforced Polymer integrated stiffened panels using different stiffener configuration like I stiffener, T stiffener, and Blade stiffener and also a flat plate is fabricated. All the panels are fabricated by hand layup method using aluminium moulds. The reinforcement phase used in this work is made of glass fiber and the matrix phase is primarily epoxy resin. Three panels for each stiffener configuration are fabricated, in total 12 panels are tested for compressive strength using Computerized Universal Testing Machine(UTM) and the results obtained are compared for the best stiffener configuration. The compressive strength analysis of integrated stiffened panels with different stiffener configuration has been studied.

***KEYWORDS:** Composites, Stiffened Panel, Stiffener Configurations & GFRP*

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INTRODUCTION

Composite materials are the latest form of material that has interesting properties such as higher strength to weight ratio which can be fabricated easily and speedily along with good electrical and thermal properties in comparison to metals. A laminated composite structure will consist of multiple layers of a composite mixture consisting of matrix materials and fiber materials. They can have similar or different properties and can be of any orientation that is purely based on the design specification. There are various unaddressed problems regarding composite laminates and they can be addressed properly by assessing the application and the usability of the particular material.

The main problem with the laminated composites is as follows: Delamination, Fiber cracking and failure of the material due to buckling. In this project, failure of the material due to buckling would be considered. The solution to this problem is to use stiffened composite panels. Stiffened composite panels are used as primary structural components in various transportation vehicles such as ship, aircraft and aerospace vehicles. In this regard, various researchers have presented their studies and the survey of the same is presented below.

Zhao and Kapania [1] developed a tool to parametrize the stiffener and studied the buckling of isotropic stiffened composite panels along with curvilinearly stiffened panels. As per the results of the analysis, the buckling load increases with increase in stiffener height up to a certain limit and further increase in height leads to constant buckling load because of panel buckling behavior. The effect due to stiffener torsional stiffness on buckling load has no influence when panel buckle in global mode and it increases in antisymmetric manner. Curvature and location of stiffener influence the buckling load and deformation shape after buckling.

Kolanu et al. [2] studied the compressive performance of Glass Fiber Reinforced Polymer stiffened panels using Digital Image Correlation. In unstiffened GFRP samples, the panel is strictly subjected to compressive loads only and due to the exhibition of high out-of-plane displacement at peak load levels, both tensile and compressive strains are observed (collapse of the panel in post-buckling session is observed). In the case of stiffened panels, bending tensile strain influences and as a result, the axial compressive strain is reduced due to the stiffener. The longitudinal strain field is largely compressive with a very small tensile region (local crushing followed by local buckling of skin was observed). T-stiffeners were best to be found for resisting strains due to bending and high load carrying capacities.

Zhu et al. [3] investigated the performance of stiffness due to stiffener on the buckling and post-buckling behaviors of composite panels with stiffeners. Equivalent compression stiffness increases as buckling load reduce and it has a minor effect on final failure strength of composites that is made up of stiffened panels. Impact of skin thickness on failure strength and the resulting buckling load is observed that shows the effect which is more compared to that of stiffener stiffness. Under uniaxial compression, a collapse of the panels is mainly because of local buckling of skin due to interface bonding between the stiffener and the skin.

Ge et al. [4] experimentally and numerically investigated the stiffened composite curved panel, using the Finite element method, Pseudo-damping method and viscous regularization technique, under in-plane and shear bending. The outcome of a load test when well in agreement with the simulation results. The double curved picture frame was designed for this test. Buckling and post-buckling behavior of panels with curvature were studied in detail.

Parlapalli et al. [5] investigated the buckling due to delamination on stitched composite laminates. Kevlar thread and Tawron thread are the threads used here. Buckling loads were calculated using the Southwell test, Vertical displacement technique and also with Membrane strain plot methods. Critical length of delamination was found to be based on the effect of stitching and was observed for both the thread types. Kevlar thread has high stiffness, higher knot tensile strength and lower tensile modulus of elasticity when compared to Twaron thread. Thus, Kevlar thread was found to be best of longer delamination. Among the three methods, Membrane plot method gives the best results.

Ndgomo et al. [6] studied the buckling behavior of the stiffened plate, using Finite element buckling analysis, under biaxial compression and shear. Using the reduced stress method with correction factor involved, following case studies on buckling under sigma_x, sigma_z and biaxial compression were studied. The inclusion of buckling verification factor V results in much better prediction under biaxial compression. For the entire panel, V is directly related to verification of longitudinal stiffeners.

Sudhir Sastry et al. [7] analyzed the buckling of thing wall stiffened composite panels. ABAQUS software package was used for the simulation. While the panel with supporting stiffener was made of same material, carbon epoxy was found to poses higher buckling strengths. If the panel and stiffener were made of different material, the E-glass panel

carbon epoxy stiffener was found to poses higher buckling loads. Load carrying capacity of panels with composites as the primary material was found to decrease with a decrease in the number of stiffeners. Composite panel with I-shaped stiffeners was found to hold the maximum load carrying capability.

Melin and Schon [8] experimented the delamination growth and buckling behavior on impacted composite specimens subjected to fatigue load. It was found that, during compression on fatigue loading, buckling occurs and it drives to the delamination growth, which controls fatigue failure. In the quasi-isotropic specimen, for each specimen, a fatigue threshold compressive load was found to exist.

Ham [9] studied the interaction between plate and column buckling according to NEN-EN1993-1-5 standards. He also developed a software tool to check plate buckling for I- and box-profiles. Stiffness in the flanges of I-column was found out and guidelines for the same were produced using Finite Element Method analysis. He found that single geometric imperfection was not equal to the real structure with real geometric imperfection and residual stresses. He also studied that, the effect of strain hardening was not present in analysis but was present in real structures. The present work is based on the literature review and concentrates on the strength analysis of stiffened panels with different stiffener configuration.

MATERIALS & EXPERIMENTAL PROCEDURES

Introduction

Glass fiber and Epoxy resin, along with hardener, are used for the fabrication of a Flat plate of dimension 300 X 200mm according to the hand lay-up method. The stiffened panel of thickness 25 mm is fabricated with Blade, Hat and T stiffener using a mold, where the stiffener's dimensions are 300 mm in Length and 25 mm of Height.

The compressive strength would be found out by the Compression Test, using a computerized UTM which is then compared to find the best stiffener configuration.

Hand Layup Method

The Hand Layup technique is the simplest, easiest and oldest method of composite processing, as the basic requirement is very minimal. Thin OHP Sheets were used on both sides with wax coating to yield good surface finish of the final product. Wax was used to avoid sticking of polymer resins to the surfaces.

Requirements

Materials Required

The materials required are

- **Fiber used:** Bi-directional Glass Fiber
- **Resin used:** Epoxy Resin LY556
- **Hardener used:** HY951
- **Resin – Hardener Proportion:** 1/10

Consumables Required

The consumables required are

- **Roller –** To remove excess resin and trapped air
- **Mold** – For fabricating Blade stiffened panels
- **Glass Beaker –** For mixing the resin and the hardener
- **Glass Stirrer** – To stir the resin and hardener
- **Weight Machine –** To weight the fiber and resin hardener mixture
- **Gloves** – To prevent the effect of Resin on our hands
- **Thinner –** To clean all necessary materials after the fabrication
- **Brush –** To apply the resin-hardener mixture over the fiber
- **C-clamp –** To clamp the T and I stiffened panels firmly
- **OHP Sheets** – For making the layup over it
- **Wax –** To prevent the layup from sticking to the OHP Sheets

Fabrication

Flat Plate

Flat Plate was fabricated by hand layup method, using reinforcement phase made up of Bidirectional Glass fiber and Epoxy polymer as the matrix phase. Glass fibers were cut into the desired dimension and then weighted in a high sensitive weighing machine. Equal amounts of epoxy resin and an appropriate proportion of hardener was mixed and stirred thoroughly using a glass stirrer. An OHP sheet was placed on the table and the first layer of the fiber was placed on the sheet. The resin mixture was applied over it using a brush. Then, an additional layer of glass fiber was placed and the roller was rolled over it to remove excess resin and trapped air inside it. Similarly, 15 layers of fibers were placed and the final layup was covered with a second OHP sheet. Weights were placed over it and allowed to cure for 24 hours. The dimensions of the flat plate were found to be 300 X 200 mm and the thickness of the panel was maintained at 5 mm.

Blade Stiffened Panel

Blade stiffened panel was fabricated by hand layup method. The experimental preparations were the same as in the flat plate fabrication. An aluminum mold was used to fabricate the panel. OHP sheets were arranged on a thinner-cleaned table. Here, the panel was made as an integrated panel by means of the mold. Layers of fibers were fabricated as in case of a flat plate. Once, the base plate was ready, the mold was placed on the layup in the desired position depending on its dimensions required, i.e., three layups were separately made, two from either side and one from the center. While integrating the panel, 5 layups were made. The final layup was covered with OHP sheets and weights were place over it to cure for 24 hours. The dimensions of the blade stiffened panel fabricated was found to be 300 X 200 mm. The thickness of the entire panel was maintained at 5 mm. The stiffener's height was 25 mm. In order to maintain the thickness as 5mm, 15 layers of fibers were taken.

T Stiffened Panel

T stiffened panel was fabricated by hand layup method. The experimental preparations were the same as in the flat plate and blade stiffened panel fabrication. OHP sheets were arranged on a thinner-cleaned table. The base plate was first fabricated. Then, another plate was fabricated to cut stiffeners. The stiffeners were made in form of ‘T’ as shown in the figure and allowed to cure. The stiffener was now attached to the base plate by means of resin-hardener mixture. The C-clamp was used to clamp the T stiffened plate firmly as shown in the figure and allowed to cure for 24 hours.

While applying a compressive load on the panel, the stiffener comes out which is referred to as the run-out. To avoid it, integration of the panel is done with 5 layers of fiber. These 5 layers were placed on all 3 sides of the panel to ensure proper integration of the stiffener with the panel. After letting it cure for 24 hours, the dimensions of the panel was 200 X 300 mm, with the height of the stiffener at 25 mm and the thickness of the whole panel was maintained at 5 mm.

I Stiffened Panel

The fabrication of the I-stiffened panel was done exactly as the T stiffened panel except that the stiffeners were made in the form of ‘I’. The dimensions were found to be the exact same as of the T stiffened panel.

Curing

The curing process was done for 24 hours to all the panels, to make the reinforcement phase and the matrix phase combine well, which makes the panel highly strong. It is then pushed to the cutting process.

Cutting

All the panels were cut to get a good finish. Water Jet cutting was the process used. The panels were fed inside the water jet cutting facility available at Ambattur and were cut into desired dimensions, which were 300 X 200 mm with a thickness of 5 mm which was maintained.

Testing

The compression test was done on all panels to determine the critical load which was used to study the compressive strength. The test was done in the Computerized Universal Testing Machine facility available at the Materials Testing Laboratory, Central Institute of Plastics Engineering and Technology, Chennai.

Computerized Universal Testing Machine

The machine can be used to test a number of material and metals in different forms and shapes by applying compressive or tensile loads. For tensile, compressive, transverse, bending, shearing, Brinell hardness etc., special attachments shall be used that helps in testing for flatbeds, chain links, wire ropes etc.,

The Computerized Universal Testing machine comprises mainly of the following constituents:

- Loading Frame
- Hydraulic System
- Electrical System

UTM Specification

The capacity of the UTM is up to 100 kN or 10 Ton. The minimum test speed is 0.01 mm/minute and the maximum test speed is 500 mm/minute. Tests like Tension testing, Compression testing, Adhesive testing, Ductility testing, Fatigue testing, Flexural testing / Bending and Shear / Torsion testing can be carried out in this UTM. The UTM has a great accuracy of ± 0.5% of reading.

Fixture Design

A fixture is a tool by means of which the panels can be placed in the UTM for the required tests. It is also designed so that the compressive load can be applied on the panels. Appropriate fixtures are designed and fabricated using mild steel for each test. 28 kg of mild steel was required of which the final fabricated fixture weighted at 20 kg.

Test Procedure

- The panels to be tested were mounted in the UTM using appropriate fixtures fabricated.
- Calibration of the load cell and strain gauge was done as per the shunt value.
- The crosshead speed as per required strain rate was selected
- The temperature of the test was kept at room temperature.
- The test speed rate &DAQ Hz speed rate as per the test required was set.
- The sample was tested up to the failure.
- The failed specimen was removed from the fixture after the test was over.

For computer data and chart

- The DAQ report test file was selected to open the raw data.
- The raw data was opened in excel sheet and the chart and data were arranged.
- Excel file was saved in the desired location.

RESULTS AND DISCUSSIONS

Flat Plate

The graph obtained for unstiffened GFRP panels is shown here. It is found that all the panels exhibited almost similar behavior. Due to the buckling initiation in the skin, the linearity in the curve was disturbed. It was observed that the peak load carried by the stiffened panels is 25.5KN, 24.6KN, and 23.4KN.

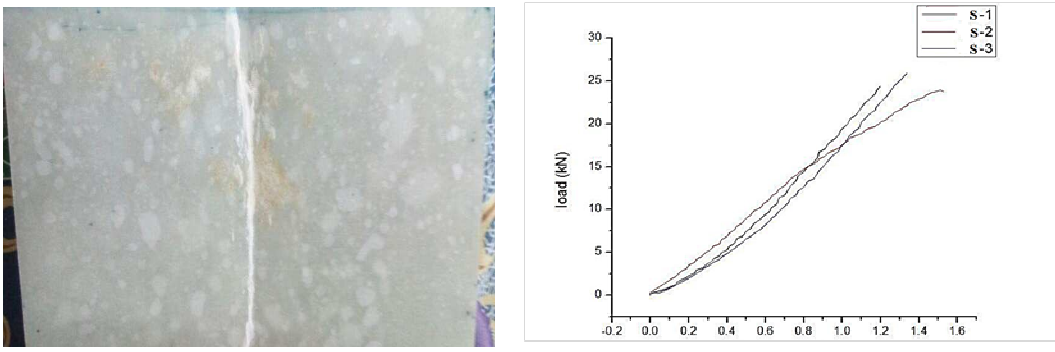

Figure 1: Flat Plate after Testing and Its Load vs Displacement Graph

Blade Stiffened Panel

The load-deformation graph of the three GFRP blade stiffened panels is presented here. Due to the occurrence of local buckling, the curves are almost nonlinear after the peak load. It is clearly visible that the failure was because of local crushing that occurred due to the stress concentration in the skin. Unlike unstiffened panels, a compressive strain was largely found than the bending effect. It is clear evident that bending of panels was greatly prevented by the presence of stiffeners. The failure loads for blade stiffener GFRP panels are 39.3KN, 40.4KN and 42.8KN.

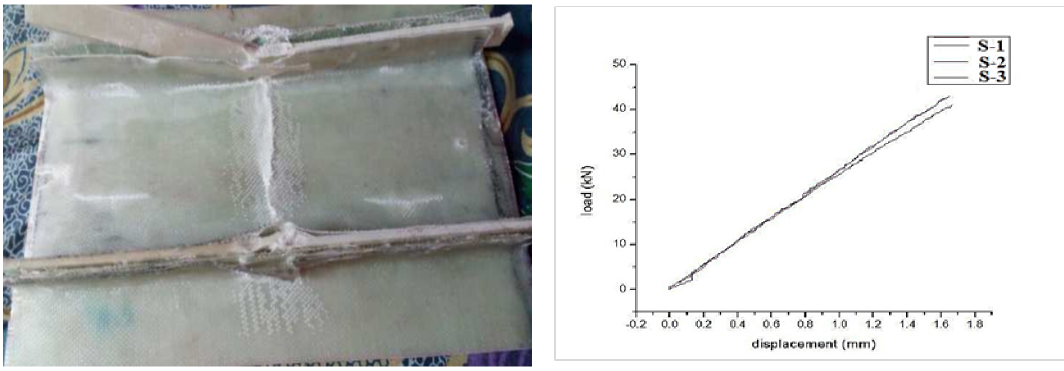

Figure 2: Blade Stiffened Panel after Testing and Its Load vs Displacement Graph

T Stiffened Panel

Three T-Stiffened GFRP panels were tested under compression and the graph was plotted. The failure loads for T-Stiffened GFRP panels was observed to be 45.4KN, 47.2KN, and 48.6KN. Similar to the blade stiffener, the large failure was due to compressive strain and T-stiffeners contributed its resistance towards bending.

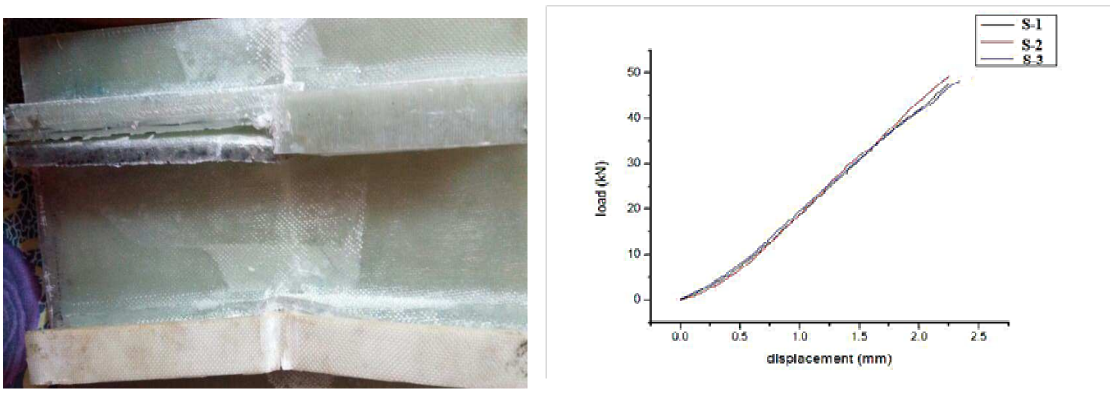

Figure 3: T Stiffened Panel after Testing and its Load vs Displacement Graph

I Stiffened Panel

The load-displacement graph obtained for the three I stiffeners tested under direct compressive load are shown here. The maximum load carried by the three I stiffened panels are 54.6KN, 53.2KN, and 51.3KN. Torsional rigidity was significantly high for I stiffened panel when compared to the other stiffened panels. But the failure loads are almost close to the T-Stiffened panels because of the configuration similarity. Therefore it is preferable to fabricate the integrated T-stiffened panel instead I-stiffened panel as the fabrication process of the former is easier when compared to the later one.

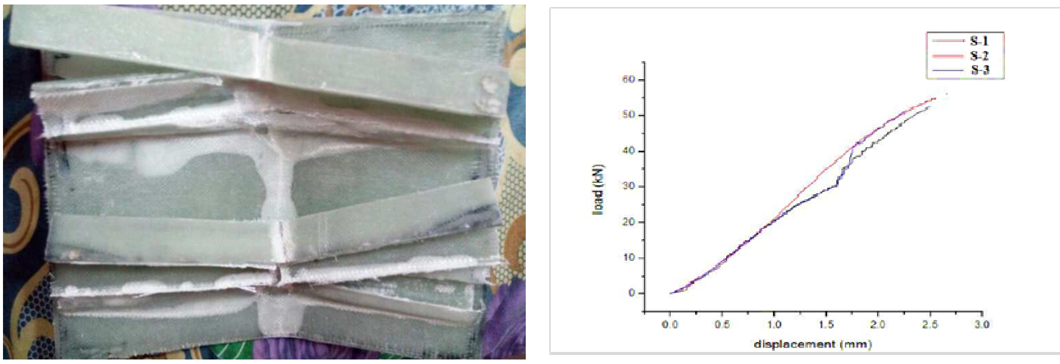

Figure 4: I Stiffened Panel After Testing and its Load vs Displacement Graph

Comparison of Failure Strengths

The comparison of failure strengths are shown in the following figure and it shows that I stiffened panel has the highest failure strength when compared to other configurations in the present study.

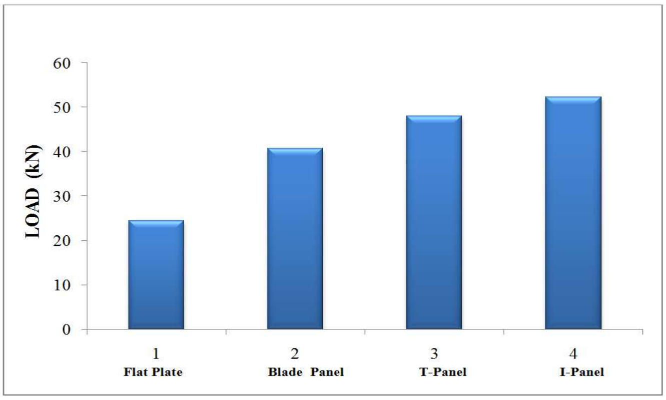

Figure 5: Comparison of Failure Strengths for Various Panels

CONCLUSIONS

A necessity for the design of high specific stiffness and strength ratio, lightweight structures had led to the development of Fiber Reinforced Polymers. FRP Panels are often subjected to compressive loads in realtime applications. This developed the stiffened composite panel. The present work provides detailed information related to studies on the strength analysis of stiffened panels. In this study, integrated stiffened GFRP panels of various stiffener configurations were studied under direct compressive load. Their performances were compared with a virgin unstiffened panel. Three specimens for each configuration were fabricated using hand layup technique. Their efficiency was compared with the load-displacement curve. Based on the test results and the load displacement curve, the following conclusions were made.

- The failure of the unstiffened panel was due to inefficient resistance to buckling that led to the collapse of the panel.
- Stiffened panels failed due to local crushing followed by local buckling of the skin.
- The strain in the unstiffened panel was due to bending that also resulted in high tensile strain distribution in the panels close to failure.
- But in stiffened panels, the presence of stiffeners prevented the out of plane deformation and only the influence of compressive strain was found.
- T stiffener and I stiffener had considerably reduced the bending strains from out of plane deformation. This led to the uniform distribution of compressive strain until failure.
- Though I stiffener exhibited better torsional resistance, the failure load of T stiffener and I stiffener were found to be very close. Hence as mentioned earlier, T stiffener can be preferably used as the fabrication of an integrated T stiffener panel was so easier when compared to the integrated I panel.
- The scope of the future work can be a parametric study using FEA with the help of test data obtained on GFRP stiffened composite panels. Design guidelines can be made by finding the optimum stiffener configuration after comparing Finite Element Analysis with test results.

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